THE ASTROPHYSICAL JOURNAL, Vol. 154, November 1968

AN INTERPRETATION OF THE PECULIAR HELIUM STAR HZ 29

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Received August 24, 1968; revised September 23, 1968

ABSTRACT

It is suggested that the variability of the peculiar helium star HZ 29 is due to nuclear-energized pulsations in a helium star of high mass.

HZ 29 is a faint high-latitude star discovered to be "decidedly blue" in color (Malmquist 1936; Humason and Zwicky 1947). It is remarkable in showing only lines of He I, which are unusually wide and shallow (Greenstein and Matthews 1957; Greenstein 1968), while undergoing a photometric variation with a period of 9 and/or 18 min (Smak, quoted in Whitford 1962; Smak 1967). Greenstein suggested a classification for the star as a helium white dwarf, which would place the star close to the Sun and account for its high galactic latitude. Smak conjectured that the photometric variability and the possibly double structure in the helium lines might be due to the presence of a close eclipsing companion, since such a short period is theoretically possible if two white dwarfs form a binary system.

In this commmunication we point out certain difficulties with the interpretation of HZ 29 as a white dwarf in a close-binary system. We then make an entirely different interpretation, which may account better for the peculiarities of the object.

The binary hypothesis meets with a number of objections, of which Smak himself pointed out the most important one. He noted that the light curve is definitely asymmetrical in shape. Moreover, it looks very much like the light curve of many known pulsating variables. A second objection is that the helium lines are too shallow and diffuse for a certain conclusion to be drawn regarding their duplicity (Greenstein and Matthews 1957). Third, no large line shifts were detected when plates were taken at short intervals by Greenstein and Matthews (however, their observations were made before the discovery of the ultrashort period). Finally, the *UBV* colors are unlike those of any known close-binary systems containing a white dwarf (see below).

The interpretation of HZ 29 as a white dwarf is also subject to question. The star has been classified as DBpnn by Greenstein, but its parallax is unknown and it does not resemble other DB stars which are known to be white dwarfs from parallax determinations (Eggen and Greenstein 1965). The star has helium lines far too wide and shallow compared with those of normal helium white dwarfs. Its colors are $B - V = -0.22$, $U - B = -1.02$ (Harris, quoted in Greenstein 1966; Smak 1967), while the other six stars classified as DB and having known colors lie strictly in the range $-0.12 \leq B - V \leq -0.06$, $-0.97 \leq U - B \leq -0.92$ (Eggen and Greenstein 1965; Greenstein 1966). The rather blue colors resemble more closely those of the blue subdwarfs, which Greenstein classifies as sdB and which may cover a very wide range of luminosity.

We suggest that HZ 29 is a luminous star of high mass and heavy composition and that its variability is due to radial pulsation. Boury and Ledoux (1965) showed that stars composed essentially of pure helium (Deinzer and Salpeter 1964) become unstable against nuclear-energized pulsations above 7–8 $M_\odot$. Since the instability is quite violent above this mass, a star finding itself with a greater mass ought quickly to eject matter and attain approximately the critical mass. This has been inferred observationally in the case of the hydrogen-burning main sequence, since no hydrogen stars are known heavier than about 60 $M_\odot$, the critical mass for hydrogen burning (Stothers and Simon 1968). Since HZ 29 undergoes a mild, periodic oscillation, it would be expected to be marginally unstable, that is, only slightly heavier than the critical mass. Adopting 7.5 $M_\odot$ as the mass of HZ 29, we find the fundamental period of radial pulsation to be exactly 18 min (Simon and Stothers 1969*a*). Evolution during helium burning is expected to change this value very little.

Since Smak found a second period of 9 min in HZ 29, we might suspect the excitation of an overtone pulsation. The first overtone and fundamental mode in the model of 7.5 $M_\odot$ have a period ratio of 0.53, as determined by transformation and interpolation of the results of Deinzer and Salpeter (1964) and of Stothers (1965). This is not far from the observed period ratio of 0.50. If the stellar mass were only slightly larger, 11 $M_\odot$, the theoretical period ratio would agree exactly (although the fundamental period would then be 22 min). However, it may be impossible to excite an overtone in such a star (Simon and Stothers 1969*b*). If 9 min represents, instead, the fundamental mode and 18 min a beat period, the inferred mass of a pure helium star is 2.5 $M_\odot$. While such a star is theoretically stable during helium burning in the core, the possibility of a thermal and pulsational instability arises when the helium energy source is transferred to a burning shell, as reported for a star of 0.75 $M_\odot$ (Rose 1967). One further possibility exists. Noels-Grötsch, Boury, and Gabriel (1967) showed that stars composed of pure carbon are unstable against nuclear-energized pulsations for all masses which burn their carbon if neutrino processes are included (but not if they are omitted). Since the neutrino processes probably exist in nature, the violence of the calculated instability suggests that a structure composed of a carbon-burning core and a thin helium envelope will also be unstable. Such a star would lie between the pure-helium and pure-carbon "main sequences." However, it is doubtful whether the helium envelope could be thick enough to increase significantly the pulsational period of a pure carbon star (1–3 min) without inducing stability (cf. Simon and Stothers 1969*a*). Therefore, in the following, we shall adopt a pulsating, pure helium star of 7.5 $M_\odot$ as the model of HZ 29. Even if the correct mass should be closer to 2.5 or 11 $M_\odot$, none of our conclusions would be qualitatively different.

Observational precedents exist for ultrashort-period pulsation. The 71-sec fluctuation in the light curve of DQ Her investigated by Walker and the author is most likely due to pulsation of the white-dwarf component (Walker 1961). "Transient periodicities" close to the period of HZ 29 have been found in SS Cyg (~16 min; Zuckermann 1961) and in BD+14°341 (~14 min; Williams 1966). Like HZ 29, these stars are probably B subdwarfs. However, they are also dwarf novae, i.e., members of close-binary systems, with relatively low masses and luminosities and relatively red colors (Mumford 1967). Nevertheless, short-period pulsation does seem to be suggested.

The spectrum of HZ 29 cannot be explained simply by high gravity, as in a white dwarf (Greenstein and Matthews 1957). In our interpretation the surface gravity would be rather low anyway—15 $g_\odot$ for a stellar radius of 0.7 $R_\odot$. Greenstein and Matthews suggested rotation as the mechanism which is broadening and possibly doubling the helium lines. If our model were rotating at a velocity close to breakup, its equatorial velocity would be of the order of 1400 km sec^{-1}. This is not inconsistent with the observed line widths (Greenstein 1958), interpreted as Doppler motion. Moreover, it is known that a number of main-sequence OB stars are in fact rotating at a velocity close to breakup (see, e.g., Aller 1953). The high inferred velocity of HZ 29 is thus consistent with its presumed derivation from a *massive* star.

The distance of HZ 29 may be readily computed on the basis of our model. A pure helium star of 7.5 $M_\odot$ has $M_{\rm bol} = -7.4$ and $T_e = 110000°$ K. Extrapolation of Kuiper's (1938) table of bolometric corrections yields B.C. $= -7$ for $T_e = 100000°$ K. A star with such a high effective temperature ought to have an intrinsic color close to that of an equivalent black body. Application of the normal reddening law to the observed colors of

HZ 29 indicates an intrinsic color closer to that of a B0 main-sequence star. But rapid rotation would certainly affect the color in the same way, and there is also the possibility of contamination of the color by a circumstellar envelope or disk. In any case, the interstellar extinction must be small. With an apparent visual magnitude $m_v = 14.2$, the distance of HZ 29 comes out to approximately 6000 pc. Its height above the galactic plane is virtually the same.

Such a large distance is not necessarily in conflict with known data. The interstellar reddening at the latitude of HZ 29 ($b^{\mathrm{II}} = +79°$) is expected to be very small even for an object located outside the Galaxy (Eggen and Sandage 1965). The proper motion of HZ 29 is either of no significance at all (Luyten and Miller 1951) or very marginal significance (Pels and Blaauw 1953; Luyten 1965*a*). The radial velocity is not known. A number of other Population I stars are observed lying at great distances above the galactic plane. The most distant objects in Blaauw's (1961) list of runaway OB stars lie 2000–3000 pc from their presumed place of origin. The spectroscopic binary HZ 22 (B2–B5 V) lies an amazing 13000 pc above the galactic plane (Greenstein, quoted in Luyten 1965*b*). These stars were either formed nearly *in situ* or ejected at high velocity out of the plane.

If HZ 29 was ejected out of the plane early in its evolutionary history, its average velocity may be simply computed. On the assumption that 7.5 $M_\odot$ represents the exposed helium core of a star evolved to the end of core hydrogen burning, the initial mass must have been $\geq 25\ M_\odot$, yielding a present age of $\leq 6 \times 10^6$ years (Stothers 1963, 1965). Hence the average velocity must have been ≥ 1000 km sec^{-1}. This is quite extraordinary. Two possible ways are suggested to avoid such a conclusion (apart from the previous speculation that the mass might be lower than 7.5 $M_\odot$). First, if the bolometric correction has been underestimated, the distance ought to be correspondingly reduced. Second, if rapid rotation of the star (inferred above) keeps it completely mixed during evolution, then its initial mass need only be $\geq 7.5\ M_\odot$, yielding a longer age of $\leq 1 \times 10^8$ years. However, Mestel (1965) has indicated the difficulty of maintaining mixing currents. Moreover, similarly high space velocities must be inferred for the *normal* stars HZ 22 and ρ Leo if they originated in the galactic plane (cf. discussion in Luyten 1965*b*). We conclude that a great distance and short lifetime for HZ 29 are not impossible.

It is finally relevant to consider the possible mechanisms which could have produced an object like HZ 29. One possibility is Blaauw's (1961) mechanism involving rapid mass loss from a moderately close stellar comparison, e.g., in a supernova explosion. The secondary is ejected at the orbital velocity. However, the expulsion of the secondary's envelope due to explosion of the primary is not possible on momentum considerations; this might also be inferred from the apparently normal spectra of Blaauw's runaway stars obtained by Wallerstein and Wolff (1965). The anomalous composition of HZ 29 must be due to some other mechanism causing loss of the hydrogen envelope. Pulsationally driven waves are one possibility (Simon and Stothers 1969*a*). Forced rotational ejection of matter is another (Limber 1964). Envelope stripping due to binary interaction is a third (Paczynski 1967). Regarding the last mechanism, an invisible companion at *moderate* separation from HZ 29 is not precluded by the observations. We have, at least, the example of the spectroscopic binary HZ 22 at large galactic height, which seems difficult to explain on Blaauw's theory. It is a very real possibility that these objects were formed nearly *in situ*.

Further studies of other helium stars for possible variability, as well as additional data on the presently known subluminous variables (Herbig 1965), would be very valuable.

It is a pleasure to thank Dr. N. R. Simon for suggesting that HZ 29 might be a *massive* helium star.

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